Station Design Considerations for Hyperloop

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Hyperloop station design is more challenging than other transport, because we must first study the technology of Hyperloop, unlike trains and aircraft where their function is well known.

Elon Musk presented Hyperloop in his brilliant Alpha proposal, but many people are unwilling to challenge any features of the design. My view is that Alpha is an unproved design concept, we should study all the design features, identify the problems, and develop solutions.

There are two areas of concern with Alpha.

- Side opening doors present serious structural and sealing challenges.
- Insufficient airflow for the air bearing skis in a near-vacuum, so wheels are proposed.

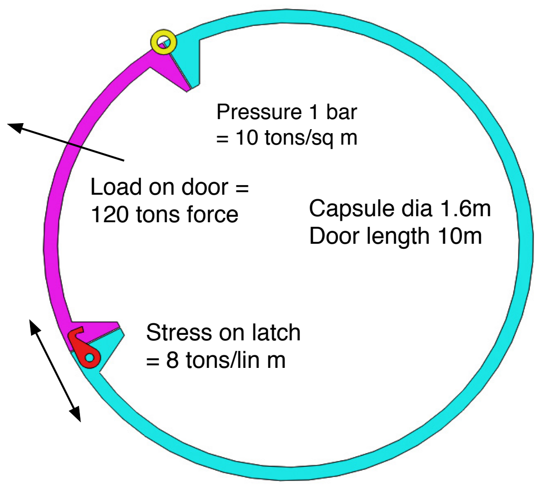
The door problem has a big affect on the design of the station, the use of wheels has the advantage of two-way travel and no turntables or loops.

Side-opening doors, the problems

Alpha proposed side opening doors look very simple in the artist's drawings. But with a massive 10 tons/sq m internal pressure, these large doors are extremely challenging.

A cylinder is a very efficient pressure vessel, the stress resolves to mainly hoop stress around the cylinder. Cut the side out of a cylinder, and all the structure is lost. Aircraft doors are relatively small, and the heavy door frame takes all the loads for the cylindrical hull, with the door simply locking into the frame.

The side doors in the pod are so large, that the door latches need to carry the tensile stress to hold the cylinder together. There is a long length of seals, which must perfect as there is no airflow into the pod to replace any leakage.

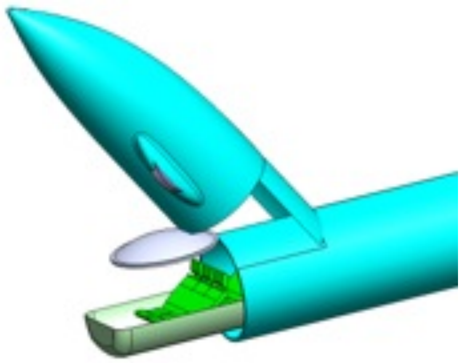


Solution - end door airlock

The solution to the side door problem is to have an airlock door on the ends of the pod, which engages with the airlock at the station, allowing the seating modules to be rolled out. The structure of the airlock doors is good, and the sealing is quite simple.

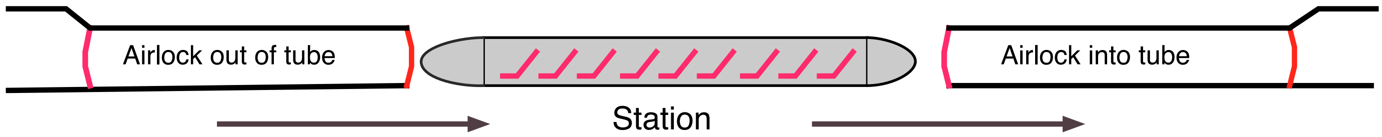
<u>This video</u> show the operation of the end doors. Since then, the design has advanced to 3 seating modules, and the tail lifting up instead of down.

<u>http://youtu.be/pWmZVTp5EqU</u>   or go to Youtube and search Hyperloop airlock



Station Design Options

The drive-through airlocks pair



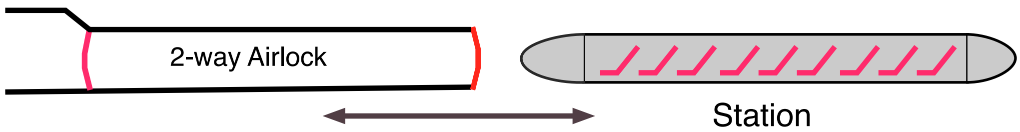
This is the classic station as shown in all vacuum-tube drawings. The pod behaves like a normal train, with the addition of two airlocks. It seems to be the simplest and most obvious solution, but it has serious problems with vacuum-pumping energy and change-over time.

The operation is as follows:-
- Pod from tube drives into first airlock.
- Air is vented into first airlock. Pod drives out into the station
- First airlock is closed and vacuum-pumped. Volume is 60 m3
- Passengers change over.
- Air is vented into second airlock, pod drives in
- Second airlock is vacuum-pumped, volume is only 20 m3 because of volume of pod.
- Pod drive into tube and departs.

The total volume to be vacuum-pumped is 80 m3 for the two airlocks. the energy cost of this is about 75 kWHr. <u>The energy cost for the whole trip is increased by about 45%.</u> by this additional pumping energy

This process could take a long time. With the door sills and limited headroom, passenger changeover would be slow, and everyone has to wait for the slowest passenger. Including airlock pumping time, it could take 10 minutes per pod. At the maximum rate of one pod/30secs, there would be <u>up to 20 pods and airlocks</u> in the station needing a very large area and long distances to walk.

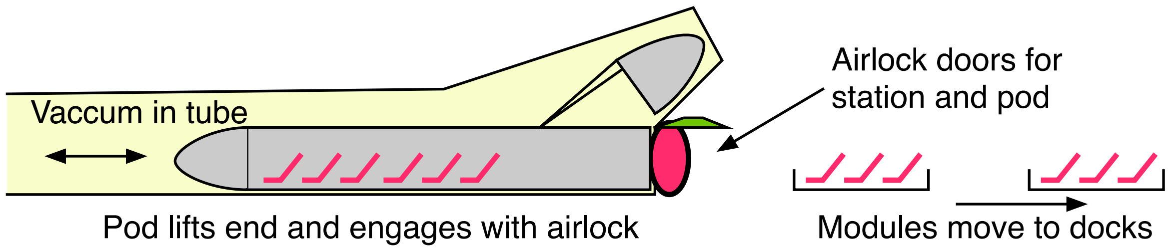
The in-out single airlock



This arrangement uses only one airlock, the pod reverses into the tube through the same airlock. This reduces the vacuum-pumping energy. But the time is similar to the drive-through airlock pair, so 20 airlocks are required.

The vacuum-pumping is reduced because only one airlock is pumped, and the pod in it reduces the volume. So the volume is 20 m3, and the energy cost for the whole trip is increased by 10%

The End Door airlock system



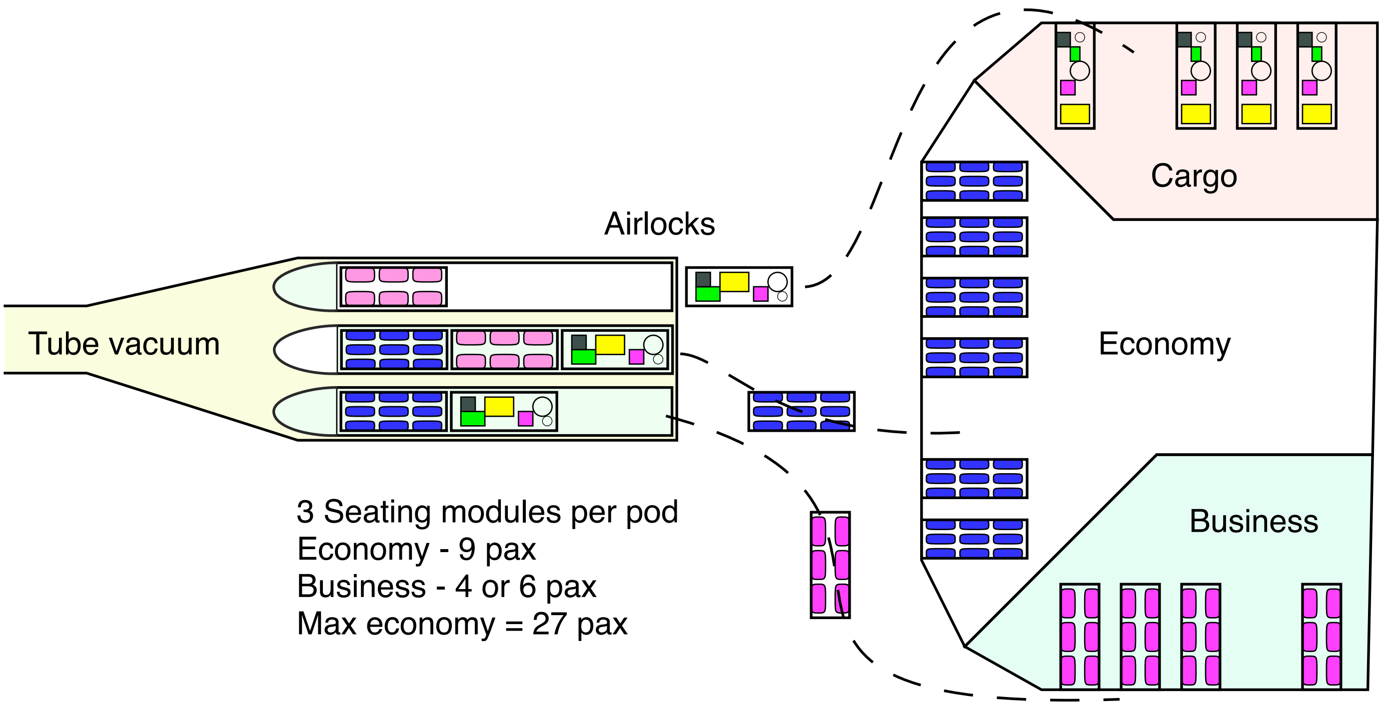
The pod stays in the vacuum, and engages with the airlock door at the station, The seating modules then drive out of the pod and go to the passenger loading docks.

There is virtually no vacuum-pumping, as the pod and station doors match.

- The nose/tail cone of the pod disengages from the hull, and lifts up
- The pod is moved into contact with the station airlock, and locks in place
- Both the airlock doors can now be opened
- The 3 seating or cargo modules are driven out to their loading docks.

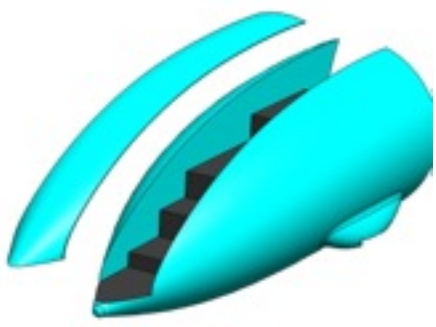
The turnaround time for each pod would be 2-3 minutes, so only 4-6 airlocks would be needed at the station. The seating modules would take about 10 minutes to change the passengers, so there would need to be up to 60 dock bays at full capacity.

Possible station layout using autonomous seating modules



Pod size and seating layouts

Emergency exit



It must be possible for the passengers to get out of the pod into the tube, in the unlikely case of total breakdown and tube pressurisation. Side doors, if used, would not open in the tube, and there is not enough room to walk past the pod. So the best solution is to have a temporary aisle in the cabin, then exits over the wheels, and through the nose and tail cones.

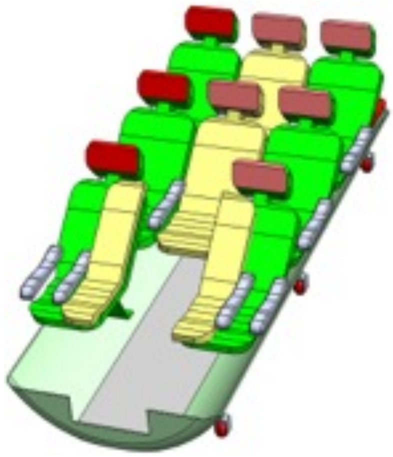
The need for the aisle means that a pod diameter of about 1,600mm (63") works well, and allows for 3 seats wide. This would make the pod 1,750 mm OD, and the tube 2,500 mm ID, for a tube/pod area ratio of 2.

The 1,200 mm wide pod as proposed in Alpha is too small to allow passengers to move along the cabin.

Seating Module options

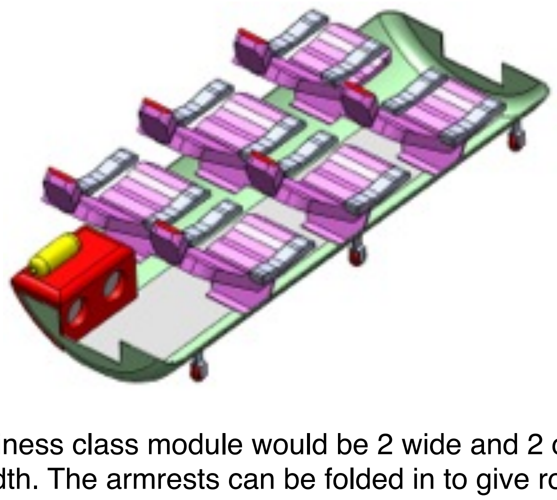
All these layouts are based on a 1,600 mm (63") pod ID. In each case the seat width is wider than the equivalent airline seats.

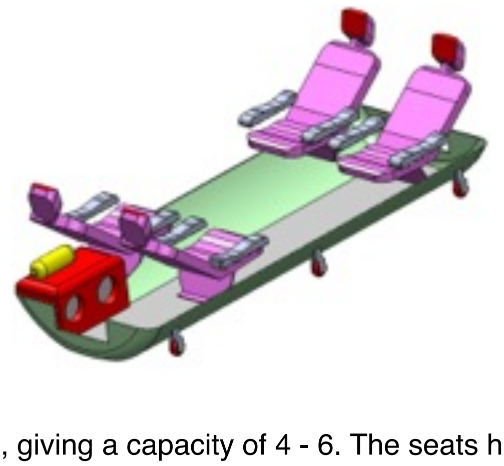
The modules are very easy for the passengers to board at the docks, because of the side access and no roof.



The economy module is 3-wide x 3 long, giving a maximum capacity for the pod of 27.

For emergency exit, the first row will move out, then the centre seat is folded to allow the next row to move. Toilet access would not be possible.





The business class module would be 2 wide and 2 or 3 long, giving a capacity of 4 - 6. The seats have a good width. The armrests can be folded in to give room in the aisle for emergency exit or possible toilet access during extended delays.

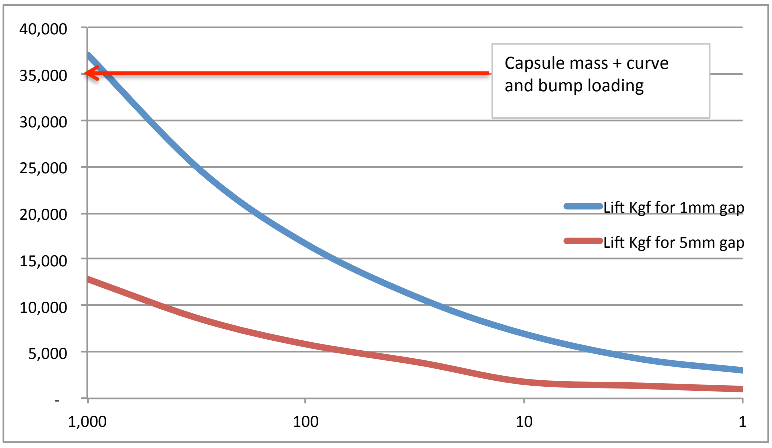
Note the air processing unit, which adds oxygen and filters out the CO2. The pod itself would only have lighting and temperature control.

Airflow problems with the air bearing skis

Alpha proposed the air bearing skis for the suspension, but maybe did not calculate the required airflow.

Air skis would obviously not work in a 100% vacuum. They are little better in the 99.9% vacuum proposed by Alpha. There have been many calculations, all showing an airflow requirement about 30 times greater than supplied by Alpha's compressor.

This graph show the lift force (Kg) for different pressures (Mbar) inside the tube, using the 164 kW compressor proposed in Alpha.



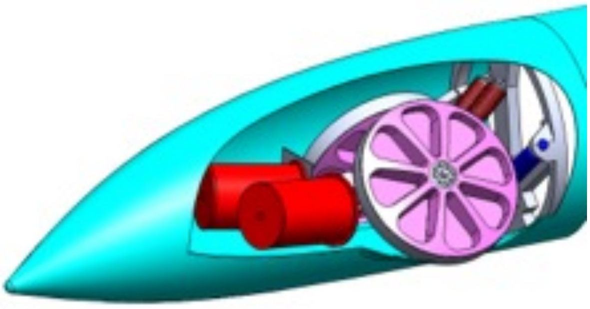
At atmospheric pressure (1000 mbar) and a 1mm gap under the skis, air skis might work. The French Aerotrain did achieve good speeds, but using considerable power for the air cushion flow. But the 1mm gap requires impractical tube tolerances, and the graph shows that the lift force is inadequate with a more realistic 5mm gap.

Reduce the tube pressure to 1 mbar as in Alpha, and the lift forces reduce dramatically. With a 1mm gap the lift force is only 8% of the requirement, and with a 5mm gap it is less than 3%. It is reasonable to conclude that air bearing skis will not work in a near-vacuum.

Alpha proposed using a viscous layer next to the tube surface. This is only a few microns (1/1000mm) thick, and would be ineffective in a near-vacuum.

Solution - wheels

If the air bearing skis are not possible due to airflow problems, wheels or maglev are the only options.



With wheels running on the correct surface in the tube, the full 1,200 km/hr should be practical. Wheels have been used at Hyperloop speeds by Andy Green at 1230 Km/hr (760 mph)

The Kantrowitz problem needs to be solved by compression of the air, in order to get the required mass flow over the pod without exceeding the speed of sound. The wheel solution compresses the air in front of the pod using the thrust of the wheels, Alpha uses internal compression.

The pod will be able to run in both directions, a great advantage in the design of the stations.